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Design, Adaptation and Convention: The Emergence of Higher Order Graphical Representations

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Abstract

To study the development of graphical conventions we had members of a simulated community play a series of graphical interaction games with partners drawn from the same pool (Experiment 1). Once the community was established, a conventional referring scheme emerged that facilitated high levels of semantic coordination, with reduced communicative effort. Next, a forced choice reaction time study (Experiment 2) demonstrated that graphical conventions developed in communities offer a distinct processing advantage when compared with those developed by isolated pairs (i.e. participants who always interact with the same partner). This is interpreted as evidence that the graphical conventions that evolve within a closed community constitute higher order cognitions, the whole being greater than the sum of its parts.

Background

Vygotsky (1981) claims that higher order cognition is a product of social interaction, that novel structures emerge as a consequence of interpersonal, as opposed to intrapersonal, communication. Hutchins (1995) shares this view, arguing that higher order cognition is a cultural product, a consequence of interaction (human-environment and human-human) that is distributed across time and space. According to Hutchins, higher order cognitions emerge from "an adaptive process that accumulates partial solutions to frequently encountered problems" (p.354). Lewis (1969, 1975) defines conventions in a comparable way, as arising from situations where a community faces the recurrent problem of coordination.

If we agree that conventions are cultural products, should we accept that they represent higher order cognitions? Using Chinese characters as an example (Figure 1), we argue that conventions are culturally evolved higher order cognitions.

Over several thousand years the original Chinese character that represents mountain (left) has evolved into its current, less complex, form (right). We argue that this change is not arbitrary; it is a result of global coordination that took place over time and space, culminating in a refined, conventional form that promotes rapid communication with reduced effort. This is an example of an evolutionary process where the whole is greater than the sum of its parts.

Figure 1. The changing form of the Chinese character that represents mountain (Vacarri & Vacarri, 1961; cited in Arbib, in press)

Having partners collaborate on a graphical referential communication task, Fay, Garrod, Lee and Oberlander (2003) studied the influence of interaction upon representational form. The task required participants to represent a concept such that their partner could identify it. Figure 2 illustrates the changing representation of Clint Eastwood over 6 games, where partners' drawing and identifying roles changed from game to game.

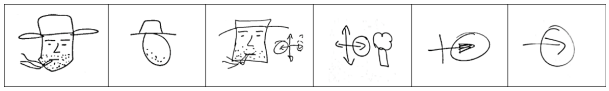

Figure 2. Partners' changing representation of Clint Eastwood over 6 games

What is initially a designed, iconic representation of Clint Eastwood develops, through a process of

adaptation and entrainment, into a simplified, symbolic representation (an arrow pointing East). Although there are obvious similarities between this process and the evolution of Chinese characters, the derived representation of Clint Eastwood does not constitute a convention in Lewis' terms. According to Lewis, a convention must be common knowledge within the wider community. At best, Figure 2 illustrates the development of a 'local' convention.

Garrod & Doherty (1994) distinguish this 'local' process from the 'global' coordination process that produces conventions. To study the development of linguistic conventions, Garrod et. al. had members of a simulated community play a series of computerized maze games with partners drawn from the same pool. After several games, community members demonstrated higher maze description scheme convergence and more closely coordinated linguistic entrainment when compared with interacting pairs, or participants drawn from a non-community (i.e. interacting partners not drawn from the same pool).

This effect was interpreted as indicating the establishment of the community, and the development of a robust referring convention. Garrod et. al. argue that referring conventions emerge on account of a global coordination constraint based upon two factors; pressure to converge upon the most popular description scheme with each new partner, and the consequent polarization of this scheme throughout the community. This is contrasted with the local coordination process evident among pair and non-community members, a process based upon the less stable heuristics of salience (pressure to choose the most salient description scheme) and precedence (pressure to choose the previously used scheme).

In much the same way as Garrod et. al. studied the development of linguistic conventions, we investigate the development of graphical conventions (Experiment 1). Furthermore, we demonstrate that these cultural products represent higher order cognitions (Experiment 2).

Experiment 1

Experiment 1 investigates the development of graphical conventions within a simulated community of drawers.

Task and Procedure

Fay et. al's (2003) graphical referential communication task was employed. This task requires participants to depict a series of concepts that can be identified by their partner. Like the game 'Pictionary', participants are not allowed to speak while drawing or communicate using text. Concepts are drawn from a list of 16 items that are known to both partners. The list was designed to contain concepts that are graphically confusable (theatre, art gallery. museum, parliament, Robert De Niro, Arnold Schwarzenegger, Clint Eastwood, drama, soap opera, cartoon, television, computer monitor, microwave, loud, homesick, poverty).

Participants play six consecutive games, using the same item set, with their partner. On each game the director, or drawer, depicts the first 12 items from an ordered list (12 items plus 4 distracters) such that their partner, the matcher, can identify each drawing from their unordered list. Item order is randomized on each game. Partners' roles, as drawer or matcher, alternate from game to game, although participants are permitted to draw in either role. Drawing took place on a standard whiteboard. Completed drawings were recorded on digital camera for later analysis.

Subjects

The community was composed of 8 undergraduate students who were paid to participate in the study.

Community Design

A simulated community was created through a series of one-to-one interactions among partners drawn from the same pool. Over 7 rounds, each participant interacted with the other members of the community. As discussed, participants completed a series of 6 consecutive graphical interaction games with each partner. The structure of the community is illustrated in Figure 3.

The community can establish itself at Round 4. This is the earliest point that the community can converge upon a conventional graphical description scheme. For example, if in Round 1 person 1 influences person 2, person 2 then influences person 3 (Round 2) and person 3 influences person 8 (Round 3), person 1 and 8 will share a comparable description scheme upon meeting in Round 4. Thus, Rounds 1-3 represent pre-convergence games, whereas Rounds 4-7 represent post convergence games.

ROUND	PAIR	PAIR	PAIR	PAIR
1	1&2	3&4	5&6	7&8
2	1&4	3&2	5&8	7&6
3	1&6	3&8	5&2	7&4
4	1&8	3&6	5&4	7&2
5	1&3	2&4	5&7	6&8
6	1&5	2&6	3&7	4&8
7	1&7	2&8	3&5	4&6

Figure 3. Structure of the simulated community

Three independent measures are employed to determine the establishment of a conventional graphical referring scheme. They are identification accuracy (i.e. participants' ability to more successfully identify conventional graphical representations), graphical complexity (i.e. the reduced effort required to negotiate the meaning of conventional graphical representations)

and graphical convergence (i.e. the greater uniformity of a conventional graphical description scheme).

Results

Identification Accuracy. Figure 4 details the identification rate (proportion of items correctly identified by matchers) of pre convergence (Rounds 1-3) and post convergence representations (Rounds 4-7) over the six games played by each pair. In pre convergence rounds there is a steady improvement in identification accuracy from games 1 to 3. After this identification rates reach ceiling level. In contrast, post convergence identification rates begin from, and are maintained at, ceiling level across games. Analysis of Variance (ANOVA) confirms these observations.

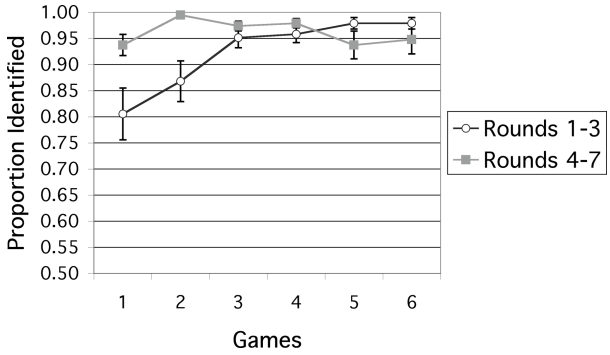

Figure 4. Mean proportion of items correctly identified by matchers in games 1 to 6 during Rounds 1-3 (pre convergence) and 4-7 (post convergence)

Proportion scores were entered into a 2 x 6 ANOVA. Analyses were conducted by subject (F_1) and by item (F_2). By subject tests used a mixed design, treating Game (1 to 6) as a within subject factor and Round (1-3 and 4-7) as between. Item tests used a within subject design. A main effect of Game $F_1(5, 130) = 6.78$, $F_2(5, 55) = 4.51$, and Round $F_1(1, 26) = 8.69$, $F_2(1, 11) = 5.97$, $p<.05$, was qualified by their interaction $F_1(5, 130) = 7.14$, $F_2(5, 55) = 6.68$ (for all results reported $p<.01$ unless otherwise stated). Tests of simple effects corroborate the observations made above; identification accuracy improves in the pre convergence rounds (1-3), $F_1(5, 130) = 11.07$, $F_2(5, 55) = 8.17$, but not in the later post convergence rounds (4-7) where identification rate is maintained at ceiling from game 1 onwards, $Fs<1.48$.

The consistently high identification rate in Rounds 4 to 7 indicates the establishment of the community and the emergence of a robust referring scheme.

Graphical Refinement. Through interaction partners minimize their collaborative effort, stripping away unnecessary graphical information, leaving only the salient properties of the image (Fay et. al., 2003). As a result, what is initially an iconic representation becomes increasingly symbolic (see Figure 2). This process of graphical refinement was evident in the community members' drawings.

Drawing complexity was measured using the Perimetric Complexity formula developed by Pelli, Burns, Farrell and Moore (accepted with minor revisions) to measure the visual complexity of letters, Complexity = Perimeter^2/Ink. This measure compares favorably with human judgments of drawing complexity (Fay et. al., 2003).

Figure 4 illustrates the mean complexity of drawings made in games 1 to 6 during Rounds 1-3 and 4-7. Mean complexity scores were calculated after the removal of scores 2.5 standard deviations (SD) from the condition mean. Extreme values were replaced with values corresponding to the mean plus or minus 2.5 SDs. Such cases accounted for 2.4% of the data.

In both the pre and post convergence rounds (Rounds 1-3 and 4-7 respectively) the complexity of community members' drawings is reduced across games. However, this effect is more marked in the early, pre convergence rounds. This observation is corroborated by ANOVA.

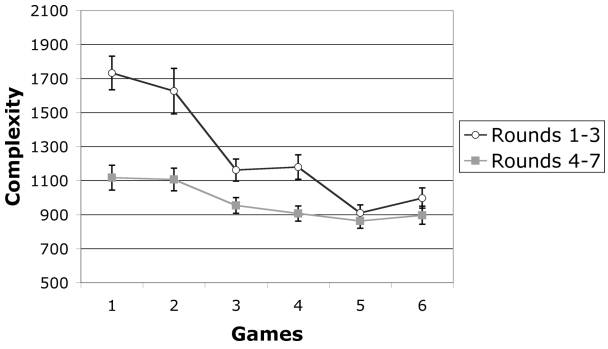

Figure 5. Mean Complexity (Perimeter^2/Ink) of pre and post convergence drawings (Rounds 1-3 and 4-7 respectively) in games 1 to 6

As before, complexity scores were entered into a 2 x 6 ANOVA. This returned a main effect of Game $F_1(5, 130) = 58.57$, $F_2(5, 55) = 34.48$, and Round $F_1(1, 26) = 13.01$, $F_2(1, 11) = 39.11$, that was qualified by their interaction $F_1(5, 130) = 15.35$, $F_2(5, 55) = 12.43$. Tests of simple effects show that graphical complexity is reduced across games in both the pre convergence rounds $F_1(5, 130) = 58.33$, $F_2(5, 55) = 39.34$, and post convergence rounds $F_1(5, 130) = 8.48$, $F_2(5, 55) = 4.24$, (Rounds 1-3 and 4-7 respectively). Between condition differences in drawing complexity in games 1 to 4, $ps<.05$, and the comparable complexity of drawings at games 5 and 6, $Fs<1.07$, explain the interaction.

Results support Garrod et al.'s distinction between local and global coordination processes and indicate the establishment of a conventional referring

scheme in Rounds 4-7. Unlike the initial exchanges in Rounds 1-3, where partners must negotiate a common description scheme, the emergence of a conventional referring scheme from Round 4 requires considerably less local negotiation.

Graphical Convergence. Graphical convergence concerns the degree to which community members' drawings converge, or become more similar, as a consequence of their interaction. To investigate the emergence of a common referring scheme, the similarity of the first drawings of each concept produced by community members at Rounds 1, 4 and 7 (i.e. pre convergence, convergence and post convergence rounds) was compared.

Figures 6, 7 and 8 illustrate the 8 community members' changing representation of cartoon at Rounds 1, 4 and 7 respectively. In addition to the reduction in graphical complexity over rounds, observe the community members' convergence upon a conventional description scheme for cartoon, in this case a Mickey Mouse like depiction, characterized two large circular ears above the head.

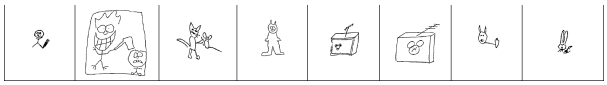

Figure 6. Community members' drawings of Cartoon at Round 1

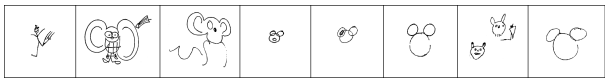

Figure 7. Community members' drawings of Cartoon at Round 4

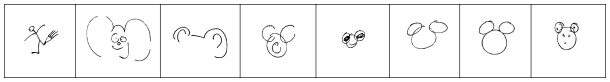

Figure 8. Community members' drawings of Cartoon at Round 7

Graphical convergence was analyzed by having 12 subjects, who had no experience of the graphical communication task, rank sets of images in terms of similarity. Each subject individually ranked three sets of 8 images (e.g. Round 1, 4 and 7 drawings of cartoon produced by each of the 8 members of the community) in terms of similarity. This was done for each of the 12 target items drawn by community members. The set of images thought to be most similar was given a rank of 1; those deemed least similar a rank of 3. The presentation order of item type (e.g. television, cartoon etc.) and round (Rounds 1, 4 or 7) was randomized.

Graphical convergence was measured by calculating the proportion of Round 1, 4 and 7 images ranked as most similar. As can be seen from Figure 9, graphical convergence increased across Rounds. A substantially higher proportion of Round 4 images were ranked as most similar when compared with Round 1 images. In addition, more Round 7 images were ranked as most similar when compared with Round 4 images.

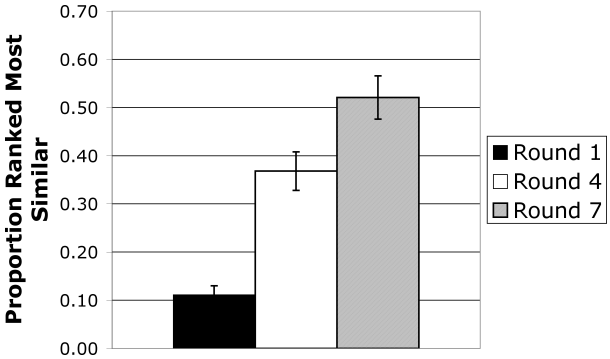

Figure 9. Mean proportion of drawings ranked most similar in Rounds 1, 4 and 7 (pre convergence, convergence and post convergence rounds respectively)

Proportion scores were entered into two repeated measures t-tests. Results were as predicted; Round 4 images were ranked as most similar more often than Round 1 images $t_1(11) = 5.82$, $t_2(11) = 2.91$, $p<.05$. This effect was less clear when Round 4 and Round 7 images were compared; by subject tests revealed a marginal effect $t_1(11) = 1.84$, $p<.10$, whereas there was no effect of round when tested by item, $p>.10$.

Consistent with the previous identification and complexity analyses, convergence tests indicate the emergence of a conventional referring scheme at Round 4. Tests show a large jump in drawing convergence from Rounds 1 to 4 and a smaller, marginally significant, increase in graphical convergence from Rounds 4 to 7. This indicates the establishment of a conventional referring scheme at Round 4, and its continued refinement in the later rounds.

Experiment 2

Having detailed the emergence of a conventional graphical description scheme in Experiment 1, Experiment 2 demonstrates that these graphical productions constitute higher order cognitions.

Experiment 2 contrasts representations that emerge as a product of design, local coordination and global coordination processes. Pre interaction drawings (i.e. subjects' first drawing of each item) represent pure design, an intrapersonal process whereby the drawer designs a representation to meet the needs of his/her partner. This is consistent with the notion of 'audience design' (Isaacs & Clark, 1987). Local coordination, or adaptation, is illustrated in the interacting pair's final drawing of Clint Eastwood in Figure 2. In this example

partners' drawings serve their local needs. Global coordination, or evolution, is exemplified by the development of a conventional referring scheme that meets the needs of the wider community (see Figure 8).

A forced choice reaction time (RT) experiment was designed to compare the processing efficiency of graphical representations that are a product of design, local coordination and global coordination processes. If graphical conventions constitute higher order cognitions they will provide a processing advantage when compared with designed or locally developed representations.

Task and Procedure

The RT experiment required subjects to make binary judgments regarding a set of learnt images. Community (Experiment 1) and isolated pair images (from Fay et. al., 2003) were used as stimuli, presented on a computer screen using PsyScope (Cohen, MacWhinney, Flatt & Provost, 1993).

24 undergraduate students, who were unfamiliar with the graphical communication experiment, were paid to act as subjects. Prior to taking part in the RT experiment, subjects learnt the identity of 48 images (50% community generated and 50% pair generated). Each image set (community and pair) was composed of 50% pre interaction images (i.e. the first drawing of each item) and 50% post interaction images (i.e. the last drawing of each item). Pre and post interaction drawings (matched by drawer) were sampled quasi-randomly from the community and isolated pair conditions. Although pre interaction drawings were more complex than post interaction drawings, there was no difference between community and isolated pair drawings (Community, *M* pre = 1796, *M* post = 906; Pair, *M* pre = 1669, *M* post = 932). Participants were judged to have learnt the images when each drawing could be identified on three consecutive presentations of the set.

Each experimental trial consisted of the following sequence; a fixation point (a small cross presented in the middle of the screen for 25 msecs), the learnt image (50 msecs), a mask (the screen was blacked out for 25 msecs) and a forced choice (text that either matched or mismatched the presented image e.g. a cartoon image followed by the text 'drama'). The time required to make a match/mismatch judgment, by key press, was recorded. Subjects completed 384 trials, with each drawing appearing 4 times in each condition.

Results

There was a 4.8% error rate on match/mismatch questions, suggesting that participants had adequately learnt the task materials. Mean RTs were calculated after the removal of times 2.5 SDs from the population mean. These extremes were replaced with values corresponding to the mean plus or minus 2.5 SDs. This accounted for 2.5% of the data.

Mean RTs for matching image and text judgments are shown in Figure 10. As predicted, the community generated graphical conventions (post interaction) were processed more rapidly than the designed (pre interaction) or locally developed pair representations (post interaction). The same pattern is evident in the mismatching text condition, but at a slower response rate (*M* match = 781 msecs; *M* mismatch = 884 msecs).

RTs were entered into a 2 x 2 x 2 ANOVA, treating Communication (Community or Pair), Image (Pre and Post) and Text (Match or Mismatch) as within subject factors. Analyses returned a main effect of Text $F_1(1, 23) = 43.79$, $F_2(1, 11) = 65.26$, indicating subjects' faster response times when the image and text stimuli matched. There was also a reliable interaction between Communication and Image $F_1(1, 23) = 10.08$, $F_2(1, 11) = 3.16$, $p = .10$. A simple effects test confirmed that community generated representations were processed more rapidly than those developed in isolated pairs $F_1(1, 23) = 5.63$, $p<.05$, $F_2(1, 11) = 6.34$, $p<.05$. Pre interaction images and post interaction pair representations were processed at a comparable rate, $Fs<1$.

The RT experiment distinguishes between representations that emerge as a product of design, local coordination and global coordination processes. The graphical conventions that evolve within the simulated community, a society composed of the pairwise interactions of its members, outperform those produced by pairs interacting in isolation. These graphical productions provide a clear example of higher order cognition, where the whole is greater than the sum of its parts.

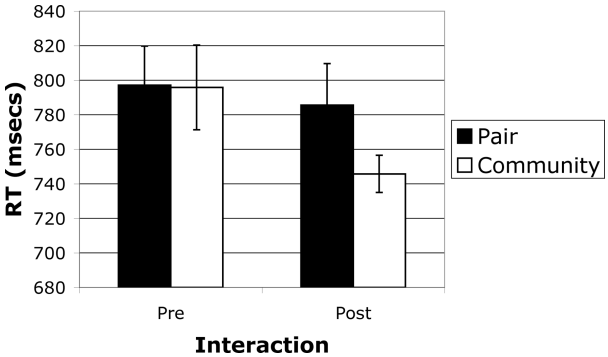

Figure 10. Mean time required to process pre and post interaction community and pair representations in the matching text condition (image and text match)

Discussion

Experiment 1 details the emergence of a conventional graphical description scheme within a simulated community of drawers. Once established, community members demonstrate near perfect semantic coordination (identification accuracy) with reduced communicative effort (graphical complexity). This is a consequence of the development of a conventional graphical description scheme (convergence). Experiment 2 distinguishes between graphical productions that develop as a product of design, local coordination and global coordination, or evolution. Graphical productions that evolve within the simulated community provide a substantial processing advantage when compared with designed or locally developed representations. Thus, conventional graphical representations constitute higher order cognitions, the whole being greater than the sum of its parts.

However, there are two potentially confounding factors in Experiment 2. Community members play more games with more partners (42 games; 6 games with each of 7 partners) than pair members (6 games with 1 partner), exposing them to a greater variety of description schemes. Number of games played can be discounted for the simple reason that isolated pairs rapidly negotiate and maintain a locally stable description scheme (Fay et. al., 2003; Garrod et. al., 1994). Community members' exposure to a greater number of exemplars is likely to have a profound effect, as people are better able to learn a prototype when exposed to its variants (Posner & Keele, 1968). However, number of exemplars alone is not enough; global coordination is necessary to derive a stable underlying representation (Garrod et. al., 1994).

So what is 'better' about the graphical conventions developed in the simulated community? We believe there are two factors at play; iconicity and systematicity. Like the present day Chinese character for mountain (Figure 1), community representations retain a degree of iconicity, i.e. once told what a drawing represents it can be 'seen' as such. Again, like the Chinese character, community drawings exhibit a degree of schematization that makes them easily differentiable. We believe these factors are responsible for the RT advantage for graphical conventions found in Experiment 2. At present this is pure conjecture. Further testing is required.

As the saying goes, 'A picture says a thousand words'. That pictures have advantages over words is supported by research showing that meaning is extracted more quickly from pictures than from words (Smith & McGee, 1980). The current study demonstrates that some pictures do this better than others.

Acknowledgments

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